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CHEMICAL PRINCIPLES OF SOIL CLASSIFICATION[1]

IT seems appropriate to preface this paper with some direct quotations from a recent publication of national authority which deal with important questions concerning the chemical principles of the soil.

I read from the "Hearings before the Committee on Agriculture of the United States House of Representatives" under date of January 28, 1908.

Mr. Whitney, Chief of the Bureau of Soils. The investigations of the Bureau of Soils, as to the causes of the deterioration of soils, and the causes that limit crop production, have changed the view-point of the entire world. The recent investigations of the bureau in soil fertility have changed the thought of the world, and several foreign governments, notably the governments of France, of Japan, of South Africa, and of Australia, have taken up these new ideas of soil fertility. (Pp. 428, 429.)

The Chairman. A few years ago the bureau issued a bulletin which was generally construed as meaning to state the proposition that all soils had all the plant food necessary for a maximum growth or crop. The inference, of course, from that was that, such being the case, one soil was as good as another. Now, I would like to know whether the popular conception of that bulletin was wrong or whether the position of the bureau has changed.

Mr. Whitney. That touches on the chemical side of the investigations of the bureau, and we have Mr. Cameron here, who did the work, and possibly he might answer that. (P. 439.)

Mr. Cameron. I would say that the main opposition to this view has been from Dr. Hopkins, from the University of Illinois.

[1] Address before the American Society of Agronomy at Cornell University, Ithaca, New York, July 11, 1908.

Again, the bureau does contend that the soil contains enough plant nutrients to support life and give good crops, for it has been shown scientifically in this country and abroad by many investigators in the past, and by many numerous recent investigations, that all soils contain practically all the common rock-forming minerals. Now, it is a principle of chemistry that when a solvent is brought in contact with a substance, that substance will go into solution until there is a state of equilibrium between the quantity of the substance outside and inside; in other words, we get a saturated solution. If these rock-forming minerals were in all soils we should have the same solution in every soil, and that has been shown to be the case. There are various variations, due to absorption, perhaps of the soil. In the first place, I must ask you gentlemen to remember that the soil and the plant and the water in the soil is moving. The soil grains are constantly moving, and the solution in the soil is constantly moving, and the growing plant is constantly moving. If a plant stops for a moment it dies. The soil solution can not stop for a moment, because it has to be moving all the time. When water falls on the soil part of it runs off the surface, and part of it runs through the surface by gravitation and comes out in the subsoil, and part of it starts and rises as soon as we get sunlight on the surface, and this part comes up in films over and through the finer spaces, and is bringing with it dissolved material from below.

The water that falls and goes through down and out goes rapidly through larger openings, and gets very little of the soluble material, because it is not long in contact with the soil grains. It gets some by reason of the fact that, as we know, our springs and rivers and wells are all soil solutions and carry mineral matter. Now, water rising by capillarity can not get very concentrated because it gets saturated with the minerals, and any excess that is contained in it is thrown out, except in extreme conditions, as in the west, and then we get alkali conditions; but under ordinary humid conditions we can not have an excess of it, and the soil solution is bringing materials from below which the plant gets, and as a matter of fact the most important discovery of the Bureau of Soils in recent years is that plants are feeding on material from the subsoils, far below where the roots go. If this is true, and there are many other arguments in the same line, it is absurd to make an analysis of the surface soil and say that is the soil that the plant is feeding on. It is not. The solution is changing around the plant roots, and it is not the surface material alone on which the plant is feeding.

Now, I am sorry to say that I shall have to make this personal, but in Illinois they have been carrying on a long series of experiments and have been making analyses of the soils, and they stated that in the soils of Illinois there are just so many pounds of phosphorus, and we know what a corn crop will take out of the soil, and therefore we can say that a corn crop will take out so much each year, and these soils will last only a certain number of years—I hesitate to say how many, I do not recollect how many—I think about fifty years. The work we carry on, which was largely given in this bulletin which has been criticized, absolutely overthrows that contention. The soil is changing; it is constantly supplying the material of the soil solution, and we know that soils have lasted thousands and thousands of years, and we have records of soils in India that have lasted two thousand years, and we know they do not wear out, and we gave the explanation why they did not, and why the land did not become a sterile waste, and it naturally aroused a feeling of opposition in the breast of this gentleman.

The Chairman. When you say that all soils contain all the elements of plant food, and there is in those soils at all times a saturated solution of which all these elemnts of plant food make a part, do you not practically say that all soils have all the plant food they need, and that it is at all times available for the plant; or is it not available for the plant if it is in a saturated solution?

Mr. Cameron. Certainly, if there is water enough; if the soil is moist.

The Chairman. Is is not, therefore, a justifiable inference from what you have said, that there is all the time in all soils enough plant food available for plant life?

Mr. Cameron. True; perfectly true as regards the mineral nutrients.

The Chairman. Then I come back again to the question, Why is it necessary, or is it in your judgment necessary, ever at any time to introduce fertilizing material into any soil for the purpose of increasing the amount of plant food in that soil?

Mr. Cameron. Not in my judgment.

The Chairman. Then in your judgment the only reason for the introduction of fertilizers is for the antitoxic effect or the mechanical effect they may have on the soil.

Mr. Cameron. Mainly that, but there are prob-

ably other functions of fertilizers that we know comparatively little about. We know that certain kinds of life, bacteria, molds, can grow in certain solutions of salts, and can not in others. It may be that fertilizers affect them. But all that is an unexplored field, and little is known about it. . . . If you will allow me to say one more word about fertilizers: What are fertilizers? What are the characteristics that a substance must have in order to be a fertilizer? It must be obtainable in large quantities. It must also be cheap. Now, the substances which are used as fertilizers in fertilizing material are substances which can be obtained in large quantities. They are substances, and are the only substances, which we can get hold of that we can get in large quantities that we can get cheap, and with one exception, that is, sodium chloride—common salt. It has not been much used as a fertilizer, because it has not any so-called plant food in it; and yet it has been used in quite a large number of experiments on quite a large scale, and wherever it has been used it has generally been found to be quite a good fertilizer. In the investigations of the bureau we have used pyrogallol. It contains no plant food, but carbon, hydrogen and oxygen, yet, nevertheless, it is a powerful fertilizer; but it can not be obtained cheaply. It is worth over $2 a pound, and nobody would think of recommending it as a fertilizer.

Mr. Pollard. Is that theory about all soils containing all the necessary constituents of plant food generally held by all scientists?

Mr. Cameron. It is accepted by the physical chemists, and by the majority of plant physiologists, and by a large percentage of the agricultural investigators.

Mr. Pollard. Throughout the country?

Mr. Cameron. Throughout this country and Europe; more in Europe than in this country. We have received far more recognition abroad than in this country, but the acceptance of it is growing very much more rapidly. Within the last two years several of us have lectured at the agricultural colleges and have explained these views, and have shown that the criticism which came to Bulletin No. 22, of which I have spoken, was largely incorrect, founded on false premises, and as a result of that we have a large mass of evidence in the form of letters, and other evidence in the fact that a number of agricultural schools are now teaching this, and are using our bulletins as text-books, that these views are accepted everywhere.

Mr. Pollard. You have reached a point where there is no question about the soundness of that view?

Mr. Cameron. I feel absolutely sure of it, and I think there is no question but that 90 per cent. of the scientific men[2] of this country would back that up.

Mr. Pollard. The reason I asked this question is that it seems to me that all of the bureaus—I do not say it with reference to this bureau in particular, but all the bureaus of the various departments at Washington—ought to be very careful about sending out matter of that kind unless they are sure, unless they have proven their ground, because it is likely to mislead and make trouble. That was the reason I asked the question.

Mr. Cameron. There has not been a publication on the subject of soil fertility going out from the Bureau of Soils—and I think I can speak advisedly, for every one has gone through my hands—in which we did not have the experimental proof long before the publication went out, and that this is being recognized I think I can claim by the fact that a number of agricultural colleges in the country are using our bulletins as text-books. I have recently come from a lecture trip extending from Louisiana to Michigan, and I found everywhere that this was being taught, and, as I say, our publications are being used for text-books. (Pp. 445–449.)

Here we have some very plain, concise, and authentic statements of the teaching of the United States Bureau of Soils concerning the chemical principles of soil fertility; and these statements are in harmony with the teaching in past years. Thus on page 64 of Bulletin 22 of the Bureau of Soils, published in 1903, we read:

That practically all soils contain sufficient plant food for good yields, . . . that this supply will be indefinitely maintained.

And on page 59 in the same bulletin were published the following statements:

In truck soils of the Atlantic coast, when 10 or 15 tons of stable manure are annually applied

[2] See report adopted by the Norfolk Convention (1907), of the committee of seven on the president's address before the Association of Official Agricultural Chemists in 1906, published as Illinois Circular 105.

to the acre, in the tobacco lands of Florida and of the Connecticut Valley, where 2,000 or 3,000 pounds of high-grade fertilizers carrying 10 per cent. of potash are used, even where these applications have been continued year after year for a considerable period of time, the dissolved salt content of the soil as shown by this method is not essentially different from that in surrounding fields that have been under extensive cultivation.

In England and in Scotland it is customary to make an allowance to tenants giving up their farms for the unused fertilizers applied in the previous seasons. The basis of this is usually taken at 30 to 50 per cent. for the first year, and at 10 to 20 per cent. for the second year after application, but in the experience of this bureau there is no such apparent continuous effect of fertilizers on the chemical constitution of the soil.

Again, on pages 21 and 22, Farmers' Bulletin 257, published in 1906, we have the following definite statements from Professor Whitney:

There is another way in which the fertility of the soil can be maintained, viz., by arranging a system of rotation and growing each year a crop that is not injured by the excreta of the preceding crop. . . . In other experiments of Laws and Gilbert they have maintained for fifty years a yield of about 30 bushels of wheat continuously on the same soil where a complete fertilizer has been used. . . . With a rotation of crops without fertilizers they have also maintained their yield for fifty years at 30 bushels, so that the effect of rotation has in such case been identical with that of fertilization.

It is not my purpose in this paper to discuss the work[3] and theories and conclusions of the Bureau of Soils, except so far as seems necessary in fixing upon some chemical principles fundamental to maintenance of the fertility of American soils.

Aside from negative factors, including the prevention of injury by disease, insects, weeds, etc., we must recognize six essential and positive factors in crop production:

First, the seed, whose value is governed by kind or variety, by previous selection or breeding, and by inherent vitality and the vigor of growth to be imparted to the young plant.

Second, the home of the plant, or the physical character of the soil, including structure, texture and tilth.

Next, the heat, light and moisture, which influence so markedly the rate of growth, and which can be controlled to a greater or less extent beyond what is done under the normal conditions of crop production.

And lastly, the plant food, a factor of no less importance to crop production than is animal food to the growth of animals.

It can not be said that any one of these factors is the most important, because every one is absolutely essential; but it can be said that of the factors that may be controlled plant food is certainly the most neglected and possibly the least understood, not only by practising farmers, but also by many agricultural teachers and investigators.

Failure to appreciate the importance of the plant-food factor is due in part to the short-sighted view too commonly given to the problem.

The great question that stands before the soil investigator, and before the American people is not how to grow good crops for the next year or even the next generation alone, but how to permanently maintain the fertility of American soils. As soon as we try to plan for permanent systems then we begin to realize the limitations of our plant-food supplies.

Another matter that has led to much confusion and misunderstanding is the common talk of available plant food, as distinct from the total supply, when as a matter of fact there is no definite line of distinction. The question as to the amount of available plant food contained in the soil at any given time is very insignificant in comparison with the question how to make plant food available. The plant food re-

[3] See Illinois Experiment Station circulars 72 and 105, and the Norfolk report (1907) of the committee of seven on the president's address of 1906, Association of Official Agricultural Chemists.

moved from the soil by a crop is not available when the crop is planted, but it must be made available during the growing season.

Plant food is made available by chemical and biochemical processes, of which amnonification and nitrification are among those best understood. The products of organic decomposition and nitrification, including various organic acids, carbonic acid, and nitric acid, are very efficient as solvents for the mineral plant food. Thus, in the conversion of organic nitrogen into nitrate nitrogen for a hundred-bushel crop of corn, the nitric acid formed is alone sufficient to convert seven times as much tricalcium phosphate into monocalcium phosphate as would be required to supply the phosphorus for the same crop; but, of course, it is not limited to this reaction. The presence of calcium carbonate, or some free base, and of oxygen, as in the aeration of the soil by tillage, will assist greatly in the decomposition of the soil and consequent liberation of plant food.

Some inorganic reactions, many organic reactions, and most biochemical reactions are not instantaneous, but long continued, and the rate of reaction is influenced by many factors, including temperature, concentration, aeration, and the presence of catalytic agencies and bacterial food-supplies. Under controlled conditions the length of time required for many such reactions is now determinable; and any soil investigation is incomplete which disregards the presence or absence of active decaying organic matter. It should be understood, too, that this term is not synonymous with humus. Partially decayed peat has no such value as fresh farm manure, clover or other green manures, even though the peat may contain as large or larger amounts of plant food, and produce similar physical effects. The one is in a sense embalmed and very inactive, while definite and continued chemical action is needed and is produced by the fresh materials.

Among the most unsatisfactory and misleading investigations are those from which the use of insoluble plant-food materials has been condemned because they have not responded when applied in the absence of adequate supplies of active organic matter.

Under similar physical conditions the amount of plant food made available during the season varies chiefly with three factors: namely, the presence of calcium carbonate, the supply of decaying organic matter, and the stock or store of fertility contained in the soil.

To supply the soil with decaying organic matter, and with lime if needed, is a necessary part of all extensive agricultural practise, and, with these provided for, the question of the total stock of plant food becomes of first importance. To illustrate this importance we may well consider some well known soils.

The early Wisconsin brown silt loam prairie, one of the commonest soil types in the Illinois corn belt, contains in the plowed soil of an acre (7 inches deep) 1,190 pounds of phosphorus and 36,250 pounds of potassium. For one hundred bushels of corn each year the total supply of phosphorus is sufficient for only seventy years, while the potassium is sufficient for more than seventeen centuries.[4]

In the unglaciated yellow silt loam hill land, the most abundant soil type in seven counties of southern Illinois, the total supply of nitrogen to a depth of 40 inches is sufficient for less than sixty such crops of corn, while the total supply of potassium to the same depth is sufficient for more than ten thousand crops, assuming in both cases that the grain is harvested and the stalks left on the land.

[4] Illinois Experiment Station Bulletin 123.

For a hundred-bushel crop of corn per acre (grain and stalks) the total supply of potassium in our peaty swamp land (seven inches deep) is sufficient for 41 years, while in the yellow-gray silt loam of the Late Wisconsin glaciation it is sufficient for 670 years.

The amounts of plant food referred to represent neither the so-called available plant food nor the acid-soluble portion, but the absolute total contained in the soil strata mentioned. Many other illustrations might be given showing enormous differences in chemical composition of different extensive types. Thus the soil at Lexington, Ky., upon which are located some of the experiment fields of that station, contains from ten to twenty times as much total phosphorus as the soil upon the university farm at Urbana, Illinois.

While the detail soil surveys and the location of boundary lines must be based primarily upon soil formation, topography, physical composition and appearance, certainly no soil classification is complete which ignores the determination of the total supplies of plant food the soils contain.

Even the figures given above may not be of the greatest interest for the production of a few crops, but shall we confine our attention to the possible production of a few more crops?

Among the great material problems of the United States of America there is one that stands supreme and incomparable; namely, to discover and to practise systems of permanent prosperous agriculture. This is a problem that no country has ever solved as we must solve it.

There is permanent agriculture in the valley of the Nile, enriched by the deposits of silt from the annual overflow. There is permanent agriculture in the rice fields of the Ganges Valley in India and the Yangtze-Kiang in China, where the soil is renewed by the frequent torrential overflows or by irrigation with water carrying suspended fertility brought from unmeasured hillsides and mountain slopes.

There is permanent agriculture, in degraded form, in many countries, on sloping hill lands whose worn-out surface soils are washed away in proportion equal at least to the rate of exhaustion of the mineral plant food; where two or three meager crops can always be grown after the land has been turned back to nature for a decade to be restored in some measure by nature's own method of covering the land with vegetation, mold and sod, largely by the aid of legume plants and nitrogen-fixing bacteria.

There is almost permanent agriculture on the black cotton soils of India which occupy extensive level uplands, where the rainfall is all within three months and where during the nine months of drouth the soil opens every few feet with cracks a foot wide and more than ten feet deep into which more or less of the worn-out surface soil falls or is carried by the winds or torrential rains which break the drouth. Here where the natives turn the soil to a depth of two feet or more, cotton, yielding a hundred pounds of lint to the acre, is still grown, after hundreds, and possibly thousands, of years of continuous agriculture.

These deep black cotton soils of India furnish the only example of apparent permanent agriculture on land that is not renewed by overflow or by erosion or by direct applications of plant food; and even here, it may be noted, the product which leaves the farm, cotton lint, carries away but little plant food from the soil, and the average yield is only one tenth of that from our own best cotton lands.

No other country has yet solved for us America's first great material problem—to discover and to practise systems of perma-

nent agriculture—for the wheat belt, and for the corn belt, and for the cotton belt; but we believe the problem is being solved for the state of Illinois—not by theories or hypothesis, but by mathematical and chemical facts, supported by actual demonstrations in the field and on the farm in all parts of the state. So far as I have been able to learn, the oldest soil experiment fields in the United States are in Illinois, with an authentic record and history of nearly a third of a century; and extensive investigations are in progress on subsequently established fields. Lands that were once poor are becoming rich—rich in materials absolutely required to make crops. Where 12 bushels of wheat were commonly grown, 30 bushels are now produced, and in both cases the same crop rotation is practised, wheat being grown but once in four years on the same field. Where without soil treatment, in the best rotation, corn yields but 50 or 60 bushels, the present average yield on treated land is from 90 to 100 bushels, under the same crop rotation. Where clover commonly fails or yields less than a ton of hay to the acre, two to three tons are now produced on properly treated land.

How is this accomplished? Simply by knowing the chemistry of the air and of the soil and by applying that knowledge mathematically to agriculture, by drawing upon these natural sources for every element of plant food which they contain in inexhaustible amount, and by supplying from other sources such elements as it is mathematically impossible for the air or soil to furnish indefinitely. Where the soil contains a very limited amount of any element of plant food not present in the atmosphere, that element is supplied not in small quantities of high-priced soil stimulants as in the so-called "complete fertilizers" that have helped to ruin much of the lands of the eastern and southern states, but in the positive addition of plant food in larger amounts than are required for the largest crops, so that the soil becomes richer, actually and mathematically, even though large crops are removed from the land. The fertilizers thus used are not artificial, but natural, and chiefly in the same form as existed originally in our naturally rich virgin soil.

Chief among the materials that we have found it necessary to use are fine-ground phosphate rock and natural limestone, together with abundance of legume crops, which must be returned to the land either directly or in manure.

We have absolutely permanent supplies of nitrogen in the air, to be secured as needed by means of clover and other legume crops, and for our system of farming we have in our common soils almost unlimited supplies of potassium and of the other less important essential mineral elements, which may be liberated as needed by means of decaying organic matter; so that with these, as with our inexhaustible limestone deposits, we are agriculturally independent. But, as the result of hundreds of analyses[5] of soils and crops, we know that the average common prairie and upland timber soils of Illinois contain about 2,000 pounds of total phosphorus per acre-foot, and with equal chemical and mathematical accuracy we know that a hundred such crops as we are now growing on our richest and best fertilized lands remove from the soil about 2,000 pounds of phosphorus. A thousand years of such cropping would require every pound of phosphorus contained in our average soil to a depth of ten feet.

Whatever we might wish to believe, we can not alter these absolute facts. We need to conserve our supplies of phosphorus, whether in the deposits of natural phosphate rock or in our farm lands or in

[5] Illinois Experiment Station Bulletin 123.

the products of the soil, as in grain and bone and animal fertilizers. Of course, if we raise crops only half as large as are possible under our normal conditions of rainfall and sunshine, then our draft upon the soil is so much less; and if we return in farm fertilizers a part of the fertility removed in crops, we may still farther postpone the day when the soil will refuse to honor the drafts we try to make.

It would seem not only important and appropriate, but especially necessary, to emphasize these facts, if from the position of highest agricultural authority should continue the wide-spread promulgation of the remarkable theory:

> That practically all soils contain sufficient plant food for good crop yields, that this supply will be indefinitely maintained;[6] that there is another way in which the fertility of the soil can be maintained, viz., by arranging a system of rotation and growing each year a crop that is not injured by the excreta of the preceding crop;[7] and that it is not necessary ever at any time to introduce fertilizing material into any soil for the purpose of increasing the amount of plant food in that soil.[8]

In a public address before the American Society of Agronomy upon the Chemical Principles of Soil Classification, I can not conscientiously omit a protest against this teaching. That crop yields are increased by application of plant-food materials is universally and absolutely known, and this fact is of course admitted by all; but the mere admission of this absolute fact does not relieve in the least the serious menace to American agriculture of the official teaching that such applications are entirely unnecessary, that it is never necessary at any time to introduce fertilizing material into any soil for the purpose of increasing the amount of plant food in that soil.

Under this doctrine farmers are taught to use, and to depend upon, any means or method that will stimulate crop yields, with no purpose or thought of maintaining or increasing the plant food in the soil. It is held that crop rotation is sufficient to maintain the fertility of the soil, and that powerful soil stimulants, such as quicklime and salt, will also accomplish this end. On the other hand, the positive addition of valuable plant food to the soil in systems of permanent soil enrichment is distinctly discouraged, such practise being denounced as wholly unnecessary. Indeed, farmers are strongly encouraged to rob their land of its fertility to the greatest possible extent and to make no return of plant food to the soil.

Furthermore, under this doctrine there is every inducement to sell, for a trifle, not only the million tons of phosphate rock now being annually exported from this country, but still larger and more exhaustive amounts of this tremendously valuable and absolutely necessary natural resource whose conservation is of the gravest importance to the United States, and of the most far-reaching consequence to our national prosperity.

Indeed, this is a matter of such vital concern to this country, and especially to the great agricultural states, that it can not rightly be ignored; for, if these unsupported theories are generally accepted by the farmers of the United States, and if the future, in harmony with all the past, only proves that crop rotation will not permanently maintain the fertility of the soil, and that the use of soil stimulants only leads to ultimate land ruin, then who shall estimate what proportion of the farms that

[6] From page 64 of Bulletin 22 of the Bureau of Soils, published in 1903.

[7] From page 21 of Farmers' Bulletin 257, by Milton Whitney, Chief of the Bureau of Soils, published in 1906.

[8] From the Hearings before the Committee on Agriculture of the House of Representatives, on January 28, 1908, in the committee's discussion with leading members of the Bureau of Soils.

are now prosperous and capable of inaugurating and supporting systems of profitable improvement leading to permanent prosperity, would, under fifty years' struggle to practise this theory, become too completely impoverished ever to redeem themselves from ultimate land ruin?

Surely we should consider the inadequate foundation of this widely promulgated hypothesis, that *practically all soils contain sufficient plant food for good crop yields,* that *this supply will be indefinitely maintained,* that *crop rotation alone will maintain the fertility of the soil,* and that *it is not necessary ever at any time to introduce fertilizing material into any soil for the purpose of increasing the amount of plant food in that soil.*

The one theory advanced in support of this remarkable doctrine is based upon the assumption that sufficient amounts of soluble plant food are brought up from the lower subsoils by the rise of capillary water to constantly replace the plant food removed by the largest crops, and thus to permanently maintain the fertility of the surface soil. (See hearings before the Committee on Agriculture, January 28, 1908.)

It is well known that soluble materials are brought from the subsoil to the surface by capillary moisture in semi-arid countries where the water leaves the soil, not by drainage, but only by evaporation, and also that there is some little tendency in this direction in humid countries, especially in times of partial drouth, but for all normal agricultural conditions this movement is insignificant compared with the actual losses of plant food in drainage water and in crops removed.

This truth is already fully established, not only by the fact that underground drainage waters always carry off some soluble plant food, but also by the fact that in humid regions the surface soils are not richer, but much poorer, than the lower subsoils—in potassium, in magnesium, in lime, and in all other constituents that dissolve in the soil waters and that do not accumulate in the humus from plant residues. Indeed, the surface even of normal virgin soils is almost invariably markedly poorer in such mineral constituents than are the corresponding lower subsoils; so that in all countries the common method employed by geologists for ascertaining the relative age of different soils is to determine the depth of soil to which some mineral constituent, as lime, has been leached out. It is everywhere recognized, both in science and in practise, that more or less of the plant food applied to soils is lost by leaching.

One of the most potent factors in the formation of all residual soils is the process of leaching. Thus, from the leaching of disintegrated rock have soils been formed. Limestone soils were originally impure limestone rock from which a very large percentage of the original rock material has been removed by leaching. No geological fact is better established or more universally recognized. From 75 to 90 per cent. of the original rock formation is not infrequently removed by leaching in the making of residual soils.

Under ordinary circumstances, I would no more think of taking up the valuable time of this society by citing proofs of the marked and continuous losses of plant food by leaching from the surface soil, than I would to cite the proofs that the earth is round, for the one fact is as well established as the other; but under the extraordinary circumstances of the confident promulgation from the position of highest agricultural authority of the theory that the fertility of American soils will be permanently maintained by the rise of plant food in capillary moisture, I feel justified in bur-

dening you with one illustration of the hundreds that might be given.

The soil of the famous Rothamsted Experiment Station is underlain with a bed of calcium carbonate, in the form of chalk, at a depth of eight feet or more. Here, then, is certainly the ideal condition with an immense supply of lime in the lower subsoil, "far below where the roots go," from which there should be an abundance carried up to the surface by capillary moisture, in accordance with the theory that "there is a steady tendency toward an accumulation of dissolved mineral matter at the surface."[9]

Now what do we find the truth to be? Is there a steady tendency toward the accumulation of lime in the surface soil at Rothamsted?

The existing information is very complete on this point. During a period of 40 years, from 1865 to 1905, large numbers of analyses have been made of the Rothamsted soils. During that time, according to Director Hall[10] and Dr. Miller, from nine different plots on Broadbalk Field there have been the following losses of calcium carbonate per acre per annum from the surface 9 inches:

	Pounds
From Plot 2*b*	590
From Plot 3	800
From Plot 5	878
From Plot 6	1,174
From Plot 7	1,010
From Plot 8	1,174
From Plot 9	564
From Plot 10	1,045
From Plot 11	1,429

The truth is that instead of an accumulation at the surface, there has been a large loss of calcium carbonate from every plot, the total loss in 40 years ranging from 11 tons to 28 tons per acre, and varying with the manures applied and the crops produced.

Furthermore, from eight different plots on Hoos Field there have been the following average yearly losses:

	Pounds
From Plot 1*O*	1,185
From Plot 4*O*	723
From Plot 1*A*	793
From Plot 4*A*	750
From Plot 1*N*	772
From Plot 4*N*	554
From Plot 1*C*	750
From Plot 7–2	848

Here, again, every plot reported has sustained a large loss, the average being about the same as for Broadbalk Field. The investigations reported also include Agdell Field and Little Hoos Field, both of which have likewise suffered loss in about the same amount as Broadbalk and Hoos.

Surely with this common knowledge of uncompensated loss by leaching in all normal humid sections, we dare not base our definite plans for systems of permanent agriculture upon a theory that by the rise of capillary water plant food is brought from the lower subsoils sufficient to meet the needs of large crops and to maintain the fertility of the surface soil in all places and for all time; and yet this is the one foundation upon which the teaching of the Bureau of Soils rests concerning permanent supplies of plant food, and is, according to Dr. Cameron, "the most important discovery of the Bureau of Soils in recent years."

In 1839 the following statement was made in Sir Humphry Davy's "Agricultural Chemistry" (p. 343):

> Some effects attributed to exhaustion of soil may be owing to excretions from roots, injurious to the plants which have yielded them, and yet beneficial to other kinds of plants; in one instance acting the part of a poison, in the other of a manure.

[9] Cameron, in "Cyclopedia of American Agriculture" (1907), Vol. I., p. 370.

[10] *Proceedings of the Royal Society* (1905), Vol. 77.

Other literature is also cited in this ancient volume, showing that the investigation of this problem of toxic excreta from plant roots was a live question seventy years ago.

That crop rotation has great value has been recognized for centuries and nowhere has its importance been more clearly shown than on the oldest soil experiment fields at the University of Illinois, where, after 30 years of crop rotation, 58 bushels of corn per acre are still produced as an average of the last three crops, while less than 25 bushels is the average for the same three years on land where corn has been grown every year for 30 years. The value of crop rotation must be attributed to the assistance thus rendered in retarding the development and multiplication of injurious insects and fungous or bacterial diseases and possibly in avoiding injury from poisonous plant excreta, and to the addition of organic matter, which supplies some nitrogen and hastens the liberation of other essential elements; but the effect of crop rotation is always to reduce, and never to augment, the total supply of mineral plant food in the soil and subsoil.

The bank must receive deposits as well as honor checks and drafts; the merchant must purchase stock as well as sell goods; and likewise, if we are to remove continually plant food from the soil in large crops, we must give back to the soil with intelligence based at least upon the mathematical facts.

This is truly the age of science, but science means knowledge; it does not mean theory or hypothesis. One dollar taken from 100 dollars leaves not 100 dollars, but only 99 dollars. This is a scientific fact which no theory or hypothesis can nullify. Likewise when a crop removes 20 pounds of phosphorus from the soil it leaves that soil 20 pounds poorer in phosphorus than before the crop was grown. The rotation of crops or the application of salt or some other stimulant may liberate another 20 pounds of phosphorus from the soil and thus enable us to grow another crop the next year, and possibly this may be repeated for several or many years, but meanwhile the total supply of phosphorus in the soil is growing smaller and smaller year by year, until ultimately neither crop rotation nor soil stimulants can liberate sufficient phosphorus from the remaining meager supply to meet the needs of profitable crops.

It is certainly safe teaching and safe practise to return to the soil as much or more than we remove of such plant-food elements as are contained in the soil in limited amounts when measured by the actual requirements of large crops during one lifetime.

The average prairie soil of more than 20 counties in southern Illinois contains such a limited supply of phosphorus that 60 such crops as we raise on our best treated land in the corn belt would require every pound of phosphorus contained in a 12-inch stratum of the southern Illinois soil; while two centuries of such crops, if they could be grown, would completely exhaust the soil of its phosphorus content to a depth of 40 inches.

These are the oldest prairie soils in the state, both agriculturally and geologically. They are also the poorest prairie soils in the state in the total supply of every valuable plant-food element. In harmony with universal experience, these soils do not improve, but continually deteriorate with time and use where no adequate return of plant food is made. These soils are not renewed by deposits from overflow or by the removal of the depleted surface by erosion, and without the positive addition of deficient plant food the future condition of these soils must be the same as the present con-

dition of much of the level upland plains of populous China, where now exist soil areas hundreds of square miles in extent that are absolutely depopulated, the restoration of which has been called "The Problem of China."

Permanent agriculture is the only structure upon which the future prosperity of the American nation can be secured, and the absolutely essential foundation of permanent agriculture is the fertility of the soil.

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EXTRACTS FROM PRESIDENT ROOSEVELT'S MESSAGE TO THE CONGRESS

IF there is any one duty which more than another we owe it to our children and our children's children to perform at once, it is to save the forests of this country, for they constitute the first and most important element in the conservation of the natural resources of the country. There are, of course, two kinds of natural resources. One is the kind which can only be used as part of a process of exhaustion; this is true of mines, natural oil and gas wells and the like. The other, and of course ultimately by far the most important, includes the resources which can be improved in the process of wise use; the soil, the rivers and the forests come under this head. Any really civilized nation will so use all of these three great national assets that the nation will have their benefit in the future.

Just as a farmer, after all his life making his living from his farm, will, if he is an expert farmer, leave it as an asset of increased value to his son, so we should leave our national domain to our children, increased in value and not worn out. There are small sections of our own country, in the east and in the west, in the Adirondacks, the White Mountains and the Appalachians, and in the Rocky Mountains, where we can already see for ourselves the damage in the shape of permanent injury to the soil and the river systems which comes from reckless deforestation. It matters not whether this deforestation is due to the actual reckless cutting of timber, to the fires that inevitably follow such reckless cutting of timber or to reckless and uncontrolled grazing, especially by the great migratory bands of sheep, the unchecked wandering of which over the country means destruction to forests and disaster to the small homemakers, the settlers of limited means.

Shortsighted persons, or persons blinded to the future by desire to make money in every way out of the present, sometimes speak as if no great damage would be done by the reckless destruction of our forests. It is difficult to have patience with the arguments of these persons. Thanks to our own recklessness in the use of our splendid forests, we have already crossed the verge of a timber famine in this country, and no measures that we now take can, at least for many years, undo the mischief that has already been done. But we can prevent further mischief being done, and it would be in the highest degree reprehensible to let any consideration of temporary convenience or temporary cost interfere with such action, especially as regards the national forests which the nation can now, at this very moment, control.

All serious students of the question are aware of the great damage that has been done in the Mediterranean countries of Europe, Asia and Africa by deforestation. The similar damage that has been done in eastern Asia is less well known. A recent investigation into conditions in North China by Mr. Frank N. Meyer, of the Bureau of Plant Industry of the United States Department of Agriculture, has incidentally